THE GEOGRAPHIC-COMPLEX METHOD FOR THE STUDY OF CLIMATE

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[Polar Station of the Academy of Sciences, Kola Peninsula, U. S. S. R., May 1938]

FOREWORD

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Several examples could be cited of parallelism between formulations of scientific problems arrived at in Russia and in the United States, particularly from the sciences that must consider the relation of climate to phenomena of the natural landscape. In both countries the field scientist is called upon to investigate the distribution of phenomena over vast areas in which distinctions in landscape are graded according to the continuous and elusive gradations of climate. The approximately simultaneous and wholly independent formulation in the United States and in Russia of the principle of dependence of the character of soils on large-scale contrasts in climate is the most conspicuous example that comes to mind.

Parallel approaches in the two countries to the study of climate itself might be discovered without undue effort. The present article by a Russian scientist reflects a view of climatologic investigations that has recently been expressed in the United States, though in less elaborate form, by Stanley Dodge [1] and Cornelius Muller.[2] In both countries this view has developed out of efforts to fit climatic categories more accurately than they have hitherto been fitted to the realities of the natural landscape. If they can be so fitted, argue both the author of this article, and the American authors cited, then the implied equation may be reversed so as to give, for areas from which no climatic records are available, climatic categories from observations of the landscape. Tihomirov has outlined a program for an approach to climate through its reflection in the landscape that will be read appreciatively by many Americans. Some elements of his program will undoubtedly be new to the readers of the REVIEW; I call attention here only to his mention of the possibility of using data from plant biochemistry.

Tihomirov's article has been translated from his original Russian manuscript by N. T. Mirov, of the California Forest and Range Experiment Station at Berkeley.

INTRODUCTION

All contemporary methods of investigating climate are based on meteorologic observations supplied by a net of weather stations. Accordingly, a climatologist has at his disposal a more or less dense net of base points, at which the climatic elements are accurately recorded. For intermediate points the numerical characteristics of the climate are found by methods of simple interpolation and extrapolation. The validity of such calculations is sometimes rather limited. In regions of low relief, that possess a uniform topography, methods based on interpolation and extrapolation remain valid for very extensive areas, and weather stations may be located in such regions at intervals of perhaps about one hundred kilometers. But in mountainous countries where altitudinal climatic zones are sharply defined and where a checkerboard pattern of climate, caused by different types and orientations of mountain slopes, prevails, even the densest net of existing weather stations is insufficient for obtaining a true and detailed picture of the climate. Moreover, the method of direct interpolation and extrapolation for intermediate points in such country is altogether unreliable. Application of this method may lead to many serious errors. It can be stated without fear of contradiction that at present not a single mountainous country on the earth is well known climatologically.

The overwhelming majority of stationary weather stations are and will continue to be located in the immediate vicinity of populated places. Establishing weather stations far from such places is always a complicated and costly affair. It is safe to predict that the number of such stations will always be limited and that any increase in their number will be rather slow. Under these circumstances it is natural to inquire whether or not some climatologic method may be devised that will compensate for the lack of meteorologic data supplied by permanent weather stations.

CORRELATION BETWEEN GEOGRAPHIC LANDSCAPE AND CLIMATE

Climate is an inseparable component of the geographic landscape. Sometimes climate is the result of large-scale changes in the landscape, sometimes it is the cause of changes in the landscape. The interaction between changes in the landscape of a given part of the earth's surface and its climate is very complicated. It depends on variations in the quantity of solar radiation received, on changes in the relief of the continents and in the distribution of land and water on the surface of the earth. Systematic observations of solar radiation have been started only recently, and we do not know how it has changed during past geologic periods. Even if we assume that these changes were not great, nevertheless it is certain that the major tectonic processes of the past, that created and changed the relief of the continents and the distribution of land and water, were inevitably accompanied by corresponding changes in climate. From this point of view, climate is produced and changed through the operation of general changes in the geographic landscape of a given locality. The rapidity of such changes is determined by the rapidity of alternation of geologic periods.

Within any one geologic period the tectonics of a country remain without significant change; changes in the geographic landscape result from changes in climate. During times of tectonic stability, that is to say, the landscape is formed and changed under the influence of climate. These changes proceed more rapidly than climatic changes of tectonic origin, but the units of time involved are nevertheless of the order of geologic ages.

If we consider very short periods in the life of our planet, as for example the historical period, we see that certain elements (components) of a landscape, such as relief, distribution of land and water, or geographical position of a place, determine its climate. Others, such as the present regime of surficial and subterranean waters,

[1] The Climatic Hypothesis in Geography, *Science*, Vol. 87, 1938, pp. 85-86.

[2] Plants as Indicators of Climate in Northeast Mexico, *Amer. Midland Naturalist*, Vol. 18, 1937, pp. 986-1000.

vegetation and soil—and to a certain extent the fauna—are reflections of the existing climate.

In establishing the relation between the elements of the landscape and the regime of climate during the historical era, it should be kept in mind that this relation is often considerably disturbed by man. The cutting or planting of forests, cultivation of waste areas and the growing of fields of agricultural plants, large irrigation and reclamation projects, construction of extensive canals and hydroelectric power plants associated with such large artificial bodies of water as Lake Mead—all these activities influence the landscape to such an extent as to create a new phase of dynamic equilibrium between the elements of the landscape and the regime of the climate; and may in some degree even influence the climate itself.

The dependence of vegetation on climate has been recognized since Humboldt's time. As regards surficial waters, their dependence on climate was clearly expressed by Voeikov in 1884 in the following words:

> Other conditions being equal, the more precipitation and the less evaporation from soil and vegetation, the richer will be the country in running water * * * Therefore rivers (as well as lakes) are the products of climate.

The same idea, however, was expressed as early as 1666 by Isaac Vossius in his treatise *De Nili et aliorum fluminum origine*. Vossius wrote, *omnia flumina ex collectione aque pluvialis origine*. As all rivers are fed by underground waters in a greater or less degree, Voeikov's statement can also be applied to ground water. As far as soils are concerned, the theory of their climatic origin was advanced by Hilgard in 1889 and has been developed by later investigators.

THE GEOGRAPHIC-COMPLEX METHOD OF CLIMATOLOGIC INVESTIGATION

Vegetation, soil, and surficial waters, including snow and ice, cover in various combinations the whole surface of the earth. Every point on the earth, therefore, reflects in one way or another the climatic regime obtaining there. If it were possible to secure by some means a quantitative correlation between details of the elements of the landscape and elements of the climate, then the climatologist would have in his possession a means of ascertaining the climate of any place on the surface of the earth. This problem appears to be of outstanding importance when we consider what was said above concerning the existing net of meteorologic stations, the prospects of its expansion in the future, and the difficulties encountered in studying the climates of mountains and of other places having sparse populations.

In this method of climatologic investigation, the role of stationary weather stations would resemble that of the "bench marks" used in surveying. For intermediate points where direct observations are not possible, climatic data would be obtained by studying the phenomena of the landscape. Since the proposed method is based on the simultaneous observation of several elements of the landscape, it may be called the *geographic-complex method of studying climate*. It is obvious that this method cannot be considered a substitute for standard climatologic methods, but rather as a subsidiary procedure that aims to facilitate the gathering of data pertaining to the climates of the earth.

The dependence of vegetation, soil and hydrography on climatic conditions is so complicated that at a first glance any attempt to evaluate them quantitatively may appear to be a risky one. However, the returns that are promised even by a partial solution of the problem seem to be sufficient to justify an attempt. The problem as a whole is complicated enough, but a partial solution seems to be wholly feasible.

The geographic-complex method of investigating climate calls for the application of some sciences and methods that are rather foreign to contemporary climatology. It calls for the cooperation of climatology, ecology, plant biochemistry and plant physiology, soil science, hydrology, and geomorphology. The climatologist should divorce himself from conventional office work with figures obtained from meteorologic observations. He should instead familiarize himself with the region under investigation. He should gather his data by means of a series of climatologic expeditions and then work out his findings with a microscope or in the chemical laboratory, with the final aim of giving a picture of the climate of the region. If the geographic-complex method is to be applied practically, two problems must be solved:

First, the discovery in the landscape of climatic indicators that possess quantitative functional relations to certain elements of climate or to certain combinations of these elements; and second, the development of methods for determining "reduction factors" to be used in translating numerical values of the landscape indicators into numerical values of climatic indicators. These two problems can be solved by research at a fixed station, the results obtained in the office being verified by observation in the field. Climatologic expeditions appear to be the best field method in the geographic-complex study of climate.

CLIMATIC INDICATORS IN THE LANDSCAPE

At present only a few landscape indicators of climate are known. It is believed that through broad systematic study a number of indicators may be found, of which the most significant ones may be selected for use. In searching for indicators it is essential to avoid tying up a certain indicator too rigidly with the whole range of fluctuation of a single climatic element, or a mechanical application of the same indicator in different types of climate.

Each indicator should be used only locally, and its significance in different seasons of the year should be ascertained. Landscape indicators of climate are no more nor less than witnesses' statements given by the vegetation, soils and waters of a given locality concerning its climatic regime. All such "statements" have a very individualistic character and may be distorted by many circumstances. Therefore it appears necessary to make certain the possibility of cross-checking any climatic phenomenon with many indicators and to arrive through numerous observations at the conclusions sought. It may happen that a given indicator will reflect a certain complex of climatic elements, and again that a given element of climate will be characterized, not by one indicator, but by many indicators taken together.

In this connection, a question may arise in the future as to the necessity either of supplementing the present system of measured climatic elements with complex quantities computed from observed data, or of differentiating the elements observed at present. Finally, landscape indicators of climate should be selected so that they will characterize the results of the prolonged operation of a climatic element, of its cyclic variations and of the extreme values that it assumes.

This is of course a maximum program; but if a solution cannot be attained with the help of one indicator, it would perhaps be possible to achieve it with the aid of another or of a combination of several indicators.

Let us consider some more or less familiar climatic indicators in the landscape. The most generally familiar one is increment of tree growth. Numerous investigations, mostly carried out in the United States, have been devoted to the study of the thickness of annual rings and of growth in height, chiefly in relation to amount of precipitation and temperature of the air.

Such investigations have been conducted from a silvicultural or a paleoclimatologic point of view; sometimes they have the appearance of being mere deductions from some combination of the observational data. The results of these investigations are rather controversial. Their dubious character may be explained by the lack of a uniform methodology and by the great variety of field data. On the other hand it may be explained by the fact that in different regions the woody vegetation reacts differently to changes in climatic regime. In arid regions, for example, increment in diameter reflects chiefly the precipitation regime, while in northern latitudes, where moisture is abundant, the temperature regime is of more importance.

It is possible that a comparison of magnitude of increment in trees with magnitude of evaporation would give interesting results. Tree growth is undoubtedly also affected by temperature and moisture of the soil, but these factors in their turn are linked with air temperature and precipitation. Less known but very valuable indicators of temperature are biochemical ones. The investigations of S. L. Ivanov in the Soviet Union have shown, for example, that the iodine-number of fats contained in seeds can be used as a very accurate indicator of the temperatures prevailing in the place where the parent plant grew. Among biochemical indicators, indicators of radiation should also be mentioned.

It would appear that plant biochemistry will provide the largest number of climatic indicators. Climatologists should therefore pay the utmost attention to the possibilities that plant biochemistry offers.

Flag-like crowns of trees, especially on mountains, and probably differences in the concentric pattern of the annual rings as well, may be used as indicators of the direction of prevailing winds. In deserts the orientation of sand dunes may be used as wind indicators. Peculiarities in the location of crowns of trees in arctic regions may serve as indicators of depth of snow cover. Humidity of the air may perhaps be judged by the degree of pubescence of certain species of willows, or of other suitable plants.

The possibility is not excluded that soil qualities may be used as climatic indicators. The extent of frozen soil may be ascertained by study of the development of the root systems of plants.

Study of the regime of bodies of water has as yet been neglected by climatologists. Yet the study of the details of surface run-off in mountainous country and of the characteristics of temporary or permanent mountain streams may yield most reliable information regarding amount and intensity of precipitation. Particular attention should also be paid to the regimen of swamps.

The above list of climatic indicators is neither complete nor systematic. This list, which is adapted to the temperate zone, is given merely as an illustration, and it could of course be greatly amplified by the inclusion of a multitude of edaphic, geologic, hydrologic, geomorphologic and phenologic indicators.

For the purposes of the geographic-complex study of climate, indicators that react quantitatively to variations in the climatic elements will be most significant. But at the same time merely qualitative indicators should not be neglected. The latter probably will always predominate in number and a skillful cross-examination of such indicators may be very useful in the complicated problem of constructing a picture of the regime of the climate.

Monographic studies of individual indicators will assist in selecting the most significant ones and will constitute the most convenient procedure. These monographic studies will also help in developing the technique of gathering data pertaining to a given indicator and evaluating its seasonal and geographic significance.

DETERMINATION OF REDUCTION COEFFICIENTS (FACTORS)

The general considerations stated above are equally applicable to the second problem of the investigation of climate by the geographic-complex method; namely, the determination of the reduction factors (coefficients) that are to be used for converting the numerical values of the landscape indicators into climatic indices. These reduction coefficients would be found through comparison of the numerical values of the landscape indicators in the immediate vicinity of meteorologic stations with the numerical values of the climatic elements obtained by direct observation at the stations. The technique of solving the problem would be worked out in the actual process of determining the separate reduction coefficients. It is unnecessary to state that in calculating these coefficients, as in the definition of climatic indicators, it will be impossible to use a uniform routine approach. The most dangerous approach would be a mechanical "bookkeeping" method consisting in the comparison of the values of landscape indicators with mean annual and monthly climatic data, without a substantial preliminary understanding of the dynamic relation of the landscape indicators to the climatic elements that determine them.

Moreover, it will be impossible to assign *a priori* a permanent significance to the reduction coefficients. It is probable that these coefficients will have an annual march and will be applicable only to a certain geographic region. In practice, the methodology both of the definition of climatic indicators and of the determination of reduction coefficients should be worked out simultaneously. In the former the leading role belongs to botany, pedology, or hydrology—depending on the peculiarities of the landscape indicator used—while in the latter the leading part is played by climatology. These circumstances determine the distribution of work among different specialists until the time when climatologists become familiar with the information to be drawn from auxiliary sciences that is necessary in order that the relations existing in Nature between landscape and climate may be understood.

CONCLUSION

The present article has aimed merely to present the general ideas of the proposed method for the study of climate, and to show in broad outline a practical way of developing the method. The complexity of the relation that exists between climate and landscape is fully appreciated. But the multitude and variety of the objects in Nature that reflect climate provide a wide and promising field for the search after the indicators of climate in the landscape. Such a search, properly organized and employed on a large scale, will undoubtedly reveal means for simplifying the entire problem and will also yield a considerable amount of accessory information sufficient for the practical realization of the proposed method of climatologic investigation.